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From Impact to Insight: A Bibliometric Mapping of Research on Anthropogenic Activities

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ABSTRACT. Focusing on aquatic and marine ecosystems, this paper provides a full bibliometric review of scientific literature on anthropogenic activities and environmental impacts. The analysis based on a dataset of 1,000 published documents between 1999 and 2015, which emanated from 539 sources, considered factors such as trends in publications, thematic structure, collaboration patterns, and field conceptual development. Results indicate a well-growing body of research, this being attested by a yearly growth rate of 33.48% and an average citation rate of 64.14 citations per document, which epitomizes great scholarly influence and continued interest in the subject matter. Keyword co-occurrence networks and conceptual mapping identify the dominant themes as climate change, biodiversity, human impact, anthropogenic disturbance, and water quality, further confirming the significant position of human-driven environmental change within contemporary ecological research. Thematic analysis further divides it into two major research fields: environmental contamination and ecosystem response and management. Temporal analysis clearly shows this: earlier studies on paleoecology and historical baselines give way to the latest studies on climate change, biodiversity loss, and applied environmental management. Patterns in collaboration show a highly cooperative research landscape, ranging from 4.63 co-authors per document, which is a reflection of the interdisciplinary nature of the studies looking at complex human-environment interactions. Other bibliometric indicators, including Bradford's law and thematic mapping, also reflect a mature research structure with core journals and established knowledge hubs. From marine science perspective, findings highlight that ecosystem degradation is often linked to anthropogenic stressors such as pollution, changed land use, and climate-induced disturbances.

Keywords: *anthropogenic disturbance, biodiversity, climate change, conservation, heavy metals, human impact, pollution, water quality*

INTRODUCTION

The prime instigator of environmental change across freshwater, marine, and terrestrial ecosystems has been human activity (IPBES, 2019; Steffen et al., 2015). Resource exploitation, rapid urbanization, agricultural intensification, and industrialization have transformed natural systems, with consequences such as pollution, habitat degradation, widespread biodiversity loss, and climate-related disruptions (Halpern et al., 2015). Human pressures, such as nutrient enrichment, heavy metal pollution, coastal development, and GHG emissions, have added to this degradation of the ecological condition and interference with ecosystem functioning, particularly in marine and coastal systems (Diaz & Rosenberg, 2008; Kennish, 2002). Interacting multiple times between such human-driven factors and the global climate processes places marine biodiversity and those services underpinning human societies at even greater risk (Hughes et al., 2017; IPBES, 2019). Because of this, understanding the extent, development, and scientific focus of the research directed at anthropogenic environmental impacts has become a pressing need within both ecological science and environmental management.

Over the last 30 years, there has been a sharp increase in scientific interest in anthropogenic environmental change as scientists try to understand the impact of human activities on natural systems (Bornmann & Mutz, 2014; Haunschild et al., 2016). While localized disruptions and historical ecological reconstructions were common in early environmental studies, more recent works have turned their attention to the complex interaction among pollution, land-use change, climate change, and ecosystem dynamics (Shifting Ecosystems Review, 2023; Xu & Xiao, 2022). Such a change indicates a more excellent shift in the discipline of environmental science incorporating aerial, ecological, climate, and conservation science approaches. Thus, the extent of anthropogenic impacts has risen with a collection of studies across many disciplines, methodological approaches, and geographies.

The bibliometric approach, quite innovatively, allows for consolidating huge scientific literature and identifying new research directions, key publications, and conceptual networks within the respective discipline (Aria & Cuccurullo, 2017; Cobo et al., 2011). Using bibliometric methods, researchers build maps that outline the intellectual structure of scientific fields, thus demonstrating changes in research priorities over time by statistically analyzing the trends in publishing, the citation networks, and the co-occurrence of keywords (Aria & Cuccurullo, 2017). In recent years, considerably more attention has been paid to bibliometric methods in environmental science to evaluate the state of research on ecosystem management, biodiversity conservation, and much more, including the aspect of climate change (Bornmann et al., 2020). Such studies yield interesting results regarding the nature of scientific knowledge creation and dissemination and scientific networks.

From the perspective of marine science, bibliometric studies may provide information on the development evolution of human activities regarding studies on ecosystem resilience, environmental monitoring, and conservation approaches (Halpern et al., 2015; Hughes et al., 2017). Marine ecosystems are among the most sensitive to anthropogenic influences because they are associated with various stress factors, such as habitat loss due to coastal development, land runoff pollution, and ocean warming as a consequence of climate change (IPBES, 2019). In this regard, research on human impacts almost invariably combines ecological monitoring, technological tools—for example, remote sensing—and applied management strategies to identify measures that would offset environmental degradation and allow sustainable use of these ecosystems (Álvarez-Martínez et al., 2025; Pandey et al., 2024). Scoping out the scientific terrain in such areas would help inform prevailing themes, new subjects, and information further directing investigations and environmental policy.

The current study does a bibliometric analysis of studies pertaining to environmental change and anthropogenic activities. This study attempts to uncover the main research themes and intellectual patterns that define scientific investigations of human influences on ecosystems by analyzing publishing trends, keyword networks, conceptual structures, and thematic evolution within the literature. Through this analysis, the study aims to show the interdisciplinary nature of efforts to comprehend and mitigate human-driven ecological change and to give a thorough summary of how anthropogenic environmental research has changed over time.

METHODOLOGY

Data Source and Literature Retrieval

This study aims to evaluate the scientific progress of studies in the field of the impact of human activities and the environment. Thus, we constructed a large number of bibliometric data related to research on the impact

of human activities and the environment. In total, 1,000 cited references extracted from 539 documents, including articles, conferences, theses, and books published in the period 1999–2015 were obtained. These documents contained 39,166 referenced references associated with ecology and the environment. We extracted metadata such as author names, publication year, document type, keywords, citation counts, and source titles from the data set. The basic characteristics of the corpus are described through the summary of the descriptive statistics shown in Table 1, such as the time span of the publications, the number of sources, the citation data, the authorship, and the document classification. Total of 4,236 authors are involved in this study which points out a collaborative network existing among numerous researchers in the field of environmental science. It is also shown that journal articles account for 984 number of records in our data set. Hence, it can be concluded that research studies related to the impacts of human activities on the ecosystem are mostly spread through peer reviewed journal articles.

Bibliometric Data Processing and Analytical Framework

In this study, science-mapping technique was applied to analyze the concept, intensity and timing structure of researches about the impact of human activity on the environment by means of bibliometrics. Based on standard bibliometric techniques such as cleaning the data set to eliminate inconsistencies, searching for meaningful keywords in the titles, abstracts and texts of publications and eliminating duplicates, keyword harmonization was applied to the data set in order to combine related key words, express different meanings with the same keyword and explain all the concepts in the data set with the same keywords and analyzing the processed data set by means of the bibliometric mapping techniques to understand the publication frequency and the structural properties of the variables such as the thematic structure, the journal citation indices and the relationships between the research topics. In the study, several complementary indicators such as co-occurrence analysis, citation analysis, topic analysis and science mapping were used to understand the dynamics of anthropogenic environmental researches at different periods and different fields.

Keyword Co-occurrence Network Analysis

Using VOSviewer, term co-occurrence network analysis was applied to uncover the main topics of studies and the underlying knowledge structure presented in the dataset. It detects the underlying structures of topics and conceptual relationships through the patterns of keyword co-occurrence within publications. The co-occurrence networks in this study were constructed based on both the indexed keywords and the author-provided keywords. The network obtained from visualization helps to understand the structure of the research topic associated with the dataset in terms of the links (co-occurrence relationships) between the keywords and their size (keyword frequency). Some of the important research topics highlighted in the figure are climate change, biodiversity, human impact/anthropogenic disturbance and water quality. Other related research themes were identified by means of clustering algorithm as: aquatic ecosystem monitoring, ecological disturbance dynamics, climate change induced biodiversity changes and remote sensing and other technical monitoring techniques. The network analysis facilitates an understanding of the nature of the anthropogenic environmental studies and relationships between the key terms.

Descriptive Bibliometric Indicators

The descriptive bibliometric analysis of the dataset consisted of calculating structural characteristics of the dataset, such as publication growth rate, citation rates, document age, number of keywords and author collaboration. We are dealing with a rapidly growing field of study on anthropogenic environmental change, which is growing at a rate of 33.48% per annum. In order to obtain some insight into the characteristics of the maturity and impact of this field of study, we made use of other indicators, such as average citations per document (64.14) and average document age (14.7 years). In order to obtain insight into the collaborative nature of the research, an analysis of the authorship per publication was made, such as the average number of authors per publication, as well as the frequency of single-authored publications.

Temporal Analysis of Scientific Production and Citation Dynamics

Cited references in publications published during the study period were extracted using a commercial citation searching tool. Time trends of the number of publications and citations within any field over a given time

period can be described by means of bibliometric time-series analysis. For any publication in the dataset we calculated the citation count and used this to estimate the impact of the individual papers. The total number of publications in a given year was calculated in order to describe the development of publication productivity within the field of study over time. We developed four additional indicators that are complementary to each other and give insights into the development of the research field over time: 1) annual scientific productivity 2) average yearly citation 3) publication life-cycle of papers and 4) cumulative publication growth. The life cycle of the research domain and the assumption of normal diffusion with its characteristic stages of emergence, growth and stabilization was estimated by applying cumulative publishing curves.

Source Productivity and Journal Impact Assessment

Source productivity and impact metrics evaluated the contributions of scientific journals to anthropogenic environmental research. The influence of each journal was assessed by local h-index calculation, and its productivity by the number of papers it published. The distribution of papers across the core and peripheral journals within the field was also examined by applying Bradford's Law of Scattering, which identifies a core of very highly cited journals responsible for a large proportion of the literature published within a field. The temporal trends of publishing within key journals were also examined. Bibliometric variables, including source productivity, local impact metrics, Bradford's distribution and temporal journal production patterns were used to demonstrate these characteristics.

Keyword Frequency and Thematic Visualization

The full bibliographic dataset was subjected to keyword frequency analysis in order to uncover emerging environmental themes and prominent research subjects. A word cloud format, in which the relative size of each phrase correlates to its frequency throughout the literature, was used to aggregate and illustrate keyword occurrences. This method offers a quick visual summary of the most popular subjects in anthropogenic environmental studies. The most common keywords in the dataset included major phrases like water quality, pollution, heavy metals, biodiversity, human influence, climate change, and conservation. The various ecological and environmental themes connected to human activity were highlighted by the identification of secondary terms pertaining to invasive species, land use change, ecosystem monitoring, and nutrient dynamics.

Thematic Evolution Analysis

A thematic evolution study based on changes in keyword frequency over time was carried out to examine changes in research focus over time. Throughout the course of the study, this analysis monitors the development, persistence, and evolution of research themes. To ascertain how scientific focus evolved from early study issues to more modern themes, keywords were categorized into temporal clusters. This analysis gave insight into the changing scientific understanding of human influences on ecosystems and made it possible to identify significant shifts in environmental research objectives.

Thematic Mapping and Cluster Classification

Research subjects were categorized using a thematic mapping approach based on their density and centrality throughout the scientific literature. While density indicates the internal growth and cohesiveness of a research cluster, centrality indicates the significance of a theme in the larger research network. A two-dimensional strategy diagram that divides subjects into four quadrants—motor themes, specialty themes, basic themes, and developing or declining themes—was created by grouping keywords into thematic clusters. While niche themes indicate specialized but isolated topics, motor themes represent well-developed and influential research areas. While issues experiencing conceptual change are represented by emerging or declining themes, basic themes relate to fundamental notions with wide applicability.

Conceptual Structure Analysis Using Multiple Correspondence Analysis (MCA)

The keyword dataset was subjected to Multiple Correspondence Analysis (MCA) in order to better explore conceptual links among study subjects. By converting high-dimensional categorical data into a lower-dimensional conceptual space, multivariate statistical analysis (MCA) enables the display of keyword

relationships. The conceptual structure of anthropogenic environmental studies was shown in this study by using MCA to find clusters of linked research subjects. Keywords are arranged based on their co-occurrence associations in the resulting conceptual structure map, where closeness denotes a greater conceptual association between study topics. Two main conceptual domains emerged from the analysis: one was related to biogeochemical impacts and environmental contamination (such as pollution, heavy metals, nutrients, and sediments), while the other was concerned with ecosystem management and conservation tactics (such as coral reefs, restoration, resilience, and monitoring).
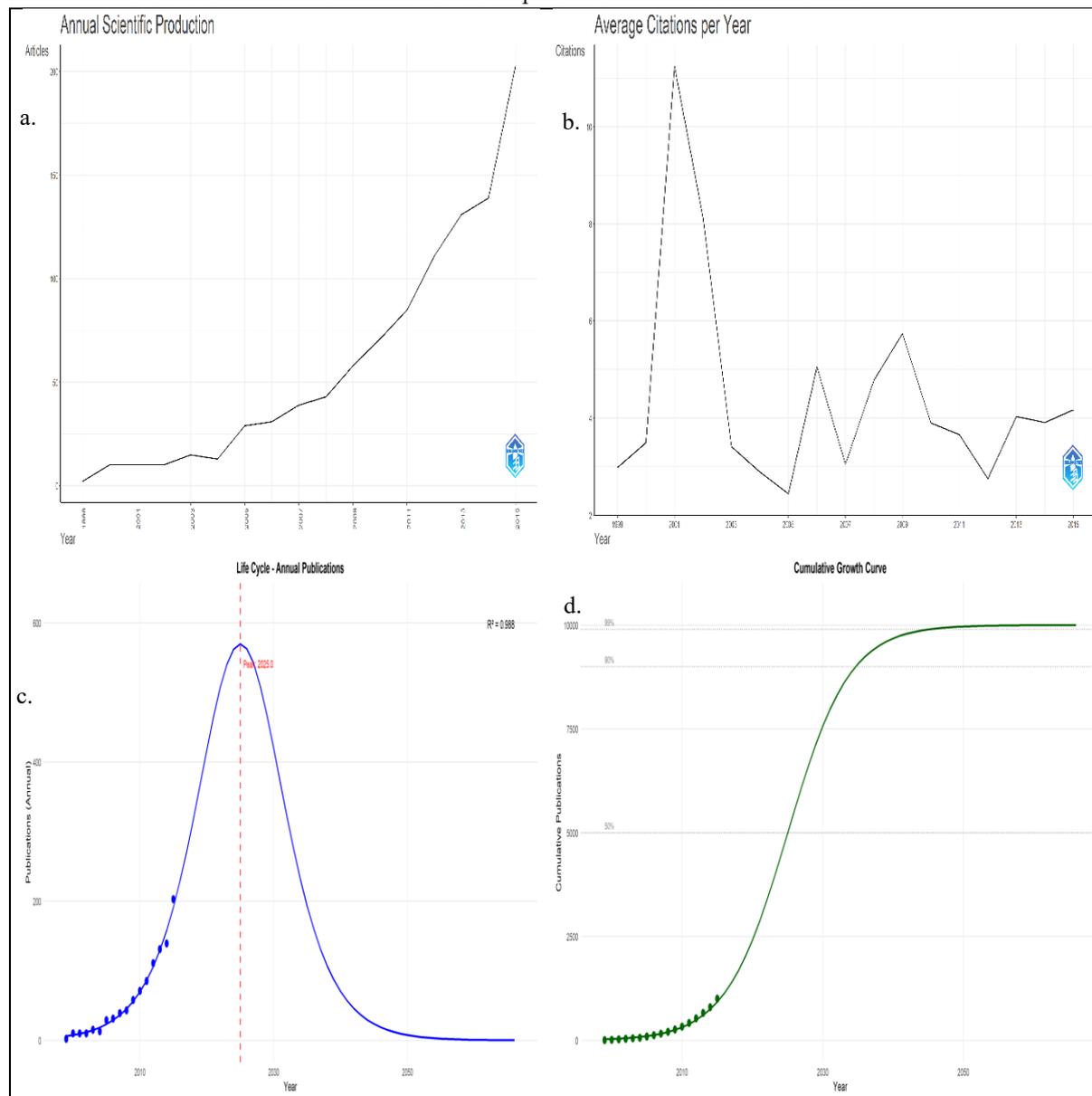
RESULTS

The dataset, which includes 1,000 documents from 539 different sources and covers the years 1999–2015, shows a wide and diverse publication base. The 33.48% annual growth rate indicates that over the examined time, research output in this area expanded quickly. With an average document age of 14.7 years and a high average citation rate of 64.14 citations per document, the dataset also demonstrates a comparatively mature body of literature, bolstered by a sizable reference base of 39,166 referenced sources. These indicators show that research on environmental change and anthropogenic implications has garnered significant scholarly interest and impacted further studies. 3,596 Keywords Plus and 3,596 author keywords are revealed by the document content analysis, indicating a broad and varied thematic coverage of the literature. The dataset has 4,236 contributors, with just 102 single-authored documents and 99 people contributing independently. This indicates that research in this field is primarily collaborative. Strong collaborative research networks are reflected in the average of 4.63 co-authors per document, which further supports this pattern. The majority of the dataset's publications (984 documents) are journal articles; books, book chapters, dissertations, and conference proceedings make up a far smaller percentage. This suggests that scientific discoveries about anthropogenic environmental impacts are mostly disseminated through peer-reviewed journals (Table 1).

Table 1. Descriptive bibliometric characteristics of the dataset used to analyze research on anthropogenic activities and related environmental topics

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	1999:2015
Sources (Journals, Books, etc)	539
Documents	1000
Annual Growth Rate %	33.48
Document Average Age	14.7
Average citations per doc	64.14
References	39166
DOCUMENT CONTENTS	
Keywords Plus (ID)	3596
Author's Keywords (DE)	3596
AUTHORS	
Authors	4236
Authors of single-authored docs	99
AUTHORS COLLABORATION	
Single-authored docs	102
Co-Authors per Doc	4.63
International co-authorships %	0
DOCUMENT TYPES	
book	1
book chapter	5
conference proceedings article	9
dissertation	1
journal article	984

The intellectual framework of research on human activity and environmental change is depicted in figure 1. Climate change, biodiversity, human influence, anthropogenic disturbance, and water quality are the largest and most central nodes, suggesting that these subjects constitute the predominant research issues in literature. Their dense connections show significant conceptual links across ecological, environmental, and management research, while their big node sizes imply high frequency of occurrence. Additionally, the graphic shows several thematic clusters, each of which represents a separate but related field of study. As an illustration of the significance of aquatic ecosystem monitoring in evaluating anthropogenic consequences, a cluster focused on water quality contains related keywords like groundwater, pollution, sediments, macroinvertebrates, and biomonitoring. Another well-known cluster connects concepts like ecosystem services, invasive species, degradation, and deforestation and is linked to climate change and biodiversity. Global environmental change is a key framework for studying anthropogenic disruptions, as evidenced by this cluster's close connection to the more general issue of human impact. Other groups, which cover subjects including disturbance, habitat loss, fragmentation, resilience, restoration, and succession, focus on ecological responses and management techniques. The network also includes a technology cluster that includes land-use change detection, remote sensing, and monitoring, indicating that contemporary observational technologies are essential for identifying and evaluating environmental changes brought on by human activity. Overall, the image shows how highly interdisciplinary anthropogenic activity research is, including ecosystem management, water quality monitoring, biodiversity conservation, and climate science.

Figure 1. VOSviewer keyword co-occurrence network

Figure 2a, which displays annual scientific production, indicates a gradual rise in publications over time, followed by a dramatic acceleration in the study period's last years. This increasing trend suggests that anthropogenic environmental impacts are receiving more academic attention, indicating that human-driven ecological change is becoming a more important scientific topic. The steady increase is a result of cumulative knowledge development, wherein later expansion in specialized research fields including climate change, biodiversity loss, and ecological disturbance was bolstered by previous foundational studies. The average annual citations are displayed in figure 2b, which exhibits significant variations with an early peak in citations followed by stabilization at moderate levels. This pattern implies that while later research contributed to diversification rather than single citation domination, early publications acted as extremely influential foundational works. A bell-shaped curve representing the research field's maturation phase is shown in figure 2c, the life-cycle model of annual publications, with peak productivity taking place around the middle of the analysis period. In contrast, figure 2d displays a cumulative growth curve with a sigmoid (S-shaped) pattern that exhibits a slow development phase at

first, fast expansion, and final stabilization. When taken as a whole, these panels show how anthropogenic activity research has evolved from a nascent field to a developed and established scientific area.


Figure 2. Temporal dynamics of scientific production and citation related to anthropogenic activities through four bibliometric indicators.

Figure 3a highlights the most pertinent sources, demonstrating that a small number of journals produce the greatest number of publications in the subject. The distribution shows that scholarly output is concentrated in a few very productive publications, with fewer papers coming from many other sources. A group of journals not only publish often but also generate highly referenced and important research (figure 3b), which shows the sources' local effect as determined by the h-index. This trend implies that knowledge generation in anthropogenic environmental studies is firmly rooted in a core set of influential scientific publications that influence scholarly discourse and research direction. Bradford's Law of scattering is demonstrated in figure 3c, which shows a traditional bibliometric distribution with a small nucleus of "core sources" producing a significant percentage of publications, followed by increasingly broader zones of less productive journals. Research is dispersed throughout numerous peripheral sources, as evidenced by the sharp drop that follows the core zone. The production of sources over time (figure 3d), which highlights the steady increase in publishing output among top journals, with a number of sources showing increased productivity in later years. The temporal patterns indicate that research platforms devoted to anthropogenic environmental change are becoming more specialized and consolidated, which reflects growing scientific interest in how humans affect ecosystems.

The largest and most prevalent terms in figure 4 are "climate change," "human impact," "anthropogenic disturbance," "conservation," and "biodiversity." These terms' prominence suggests that human-induced disturbances and climate change are major themes in the dataset that produced the word cloud. The emphasis on environmental monitoring and human stressors impacting aquatic ecosystems is further highlighted by other related high-frequency phrases like "water quality," "pollution," "remote sensing," and "heavy metals." Larger terms indicate the most often recurring study subjects or keywords in word cloud visualizations since word size correlates with frequency or importance within the dataset. Furthermore, the figure displays a number of secondary but still important terms, including "land use," "urbanization," "invasive species," "sediment," "nutrients," and "distribution," which imply that the dataset includes both direct anthropogenic pressures (such as pollution, urbanization, and heavy metals) and ecological responses (such as biodiversity patterns, species distribution, and ecosystem monitoring). Terms connected to monitoring, such "remote sensing" and "monitor," suggest that technological methods are being utilized more frequently to identify and measure environmental change. The word cloud's overall keyword structure shows that this dataset's research is primarily concerned with how human activity, climate change, ecological disturbance, and biodiversity conservation interact.

Figure 5 shows how research focus has clearly changed over time. In the early 2000s, historical and paleoecological views such as forest dynamics, late Holocene, biogeography, and historical ecology dominated prior subjects. In order to comprehend baseline ecological circumstances before significant human disturbance, these themes show an initial concentration on reconstructing historical ecosystem dynamics and long-term environmental variability. A growing interest in ecosystem reactions to environmental change and the reconstruction of previous vegetation and disturbance regimes is shown by the introduction of words like paleoecology, biological invasions, succession, and pollen analysis around the mid-2000s. The figure exhibits a noticeable shift toward topics directly related to environmental change caused by humans starting around 2010. Terms like "anthropogenic disturbance," "human impact," "climate change," "biodiversity," "conservation," and "water quality" have larger and more recent trend markers. These subjects exhibit rising phrase frequency and persistence in the dataset's most recent years, suggesting that research focus has gradually switched toward comprehending the ecological effects of human activity and global environmental change. Furthermore, in the later time, applied themes like species richness, land use, and restoration also become more prevalent, indicating that research is shifting from environmental degradation diagnosis to ecosystem management and restoration techniques.

The clusters are arranged in Figure 6a based on their density (development level) and centrality (relevance), which together show the maturity and impact of research themes in the area. Topics with stronger keyword correlations and higher document frequency are represented by larger clusters. The image shows that themes like biodiversity, climate change, and conservation form comparatively well-developed clusters, indicating that these subjects have substantial internal connections and ongoing study interest. Clusters with phrases like "human impact" and "anthropogenic disturbance" also show up close to the center of the theme space, suggesting their integrative relevance across various environmental change and ecosystem dynamics research subjects. These clusters are further divided into four thematic quadrants in Figure 6b: motor themes, niche themes, basic themes, and emerging/declining themes. Topics like pollution, heavy metals, and water quality are included in the motor themes quadrant, suggesting that these fields are both well developed and closely related to the field as a whole. The basic themes quadrant, on the other hand, includes terms like remote sensing, land use, and human influence that are extremely pertinent throughout the field but are still not as well-developed as coherent research clusters. Conversely, specialist subjects that are well-developed but have few links to the larger research network are represented by niche themes, such as monitoring, coral reefs, and the Red Sea. Lastly, the lower-left quadrant displays issues that are either freshly developing or undergoing conceptual shift within the scientific literature, such as global change and climate change.
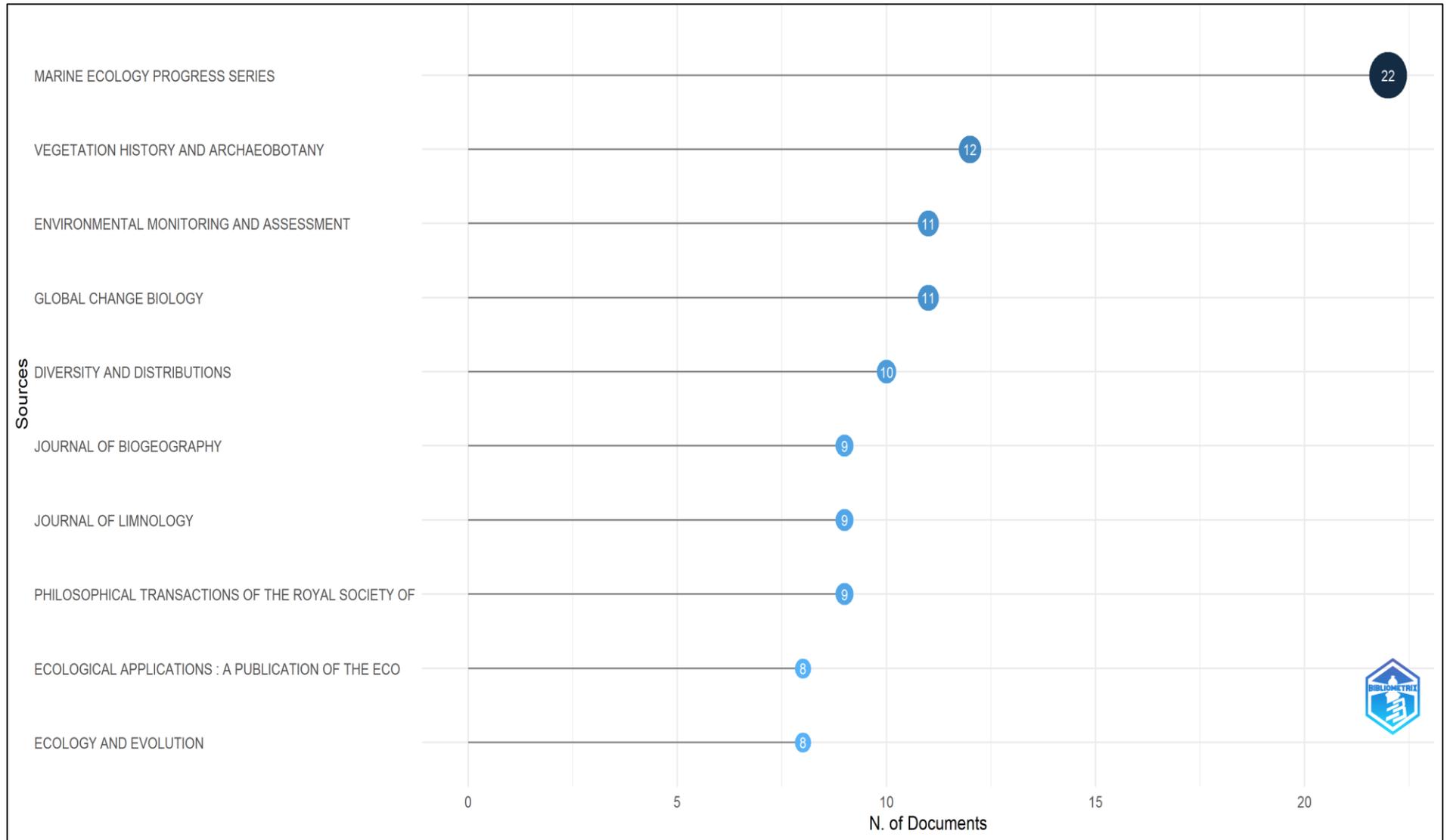
Figure 3a. Structural development of scientific literature on anthropogenic activities based on most relevant sources.
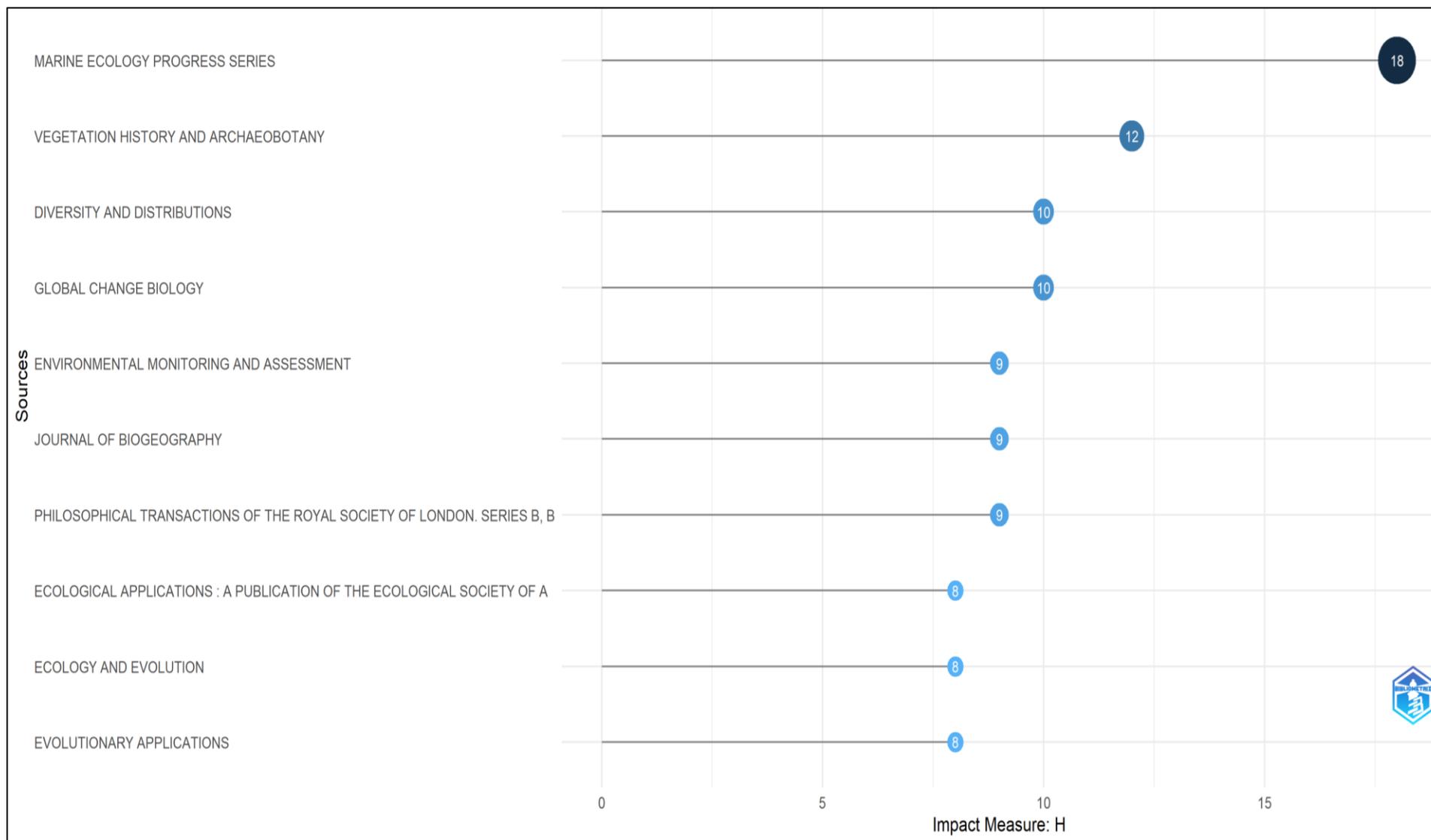
Figure 3b. Structural development of scientific literature on anthropogenic activities based on sources local impact by H index.
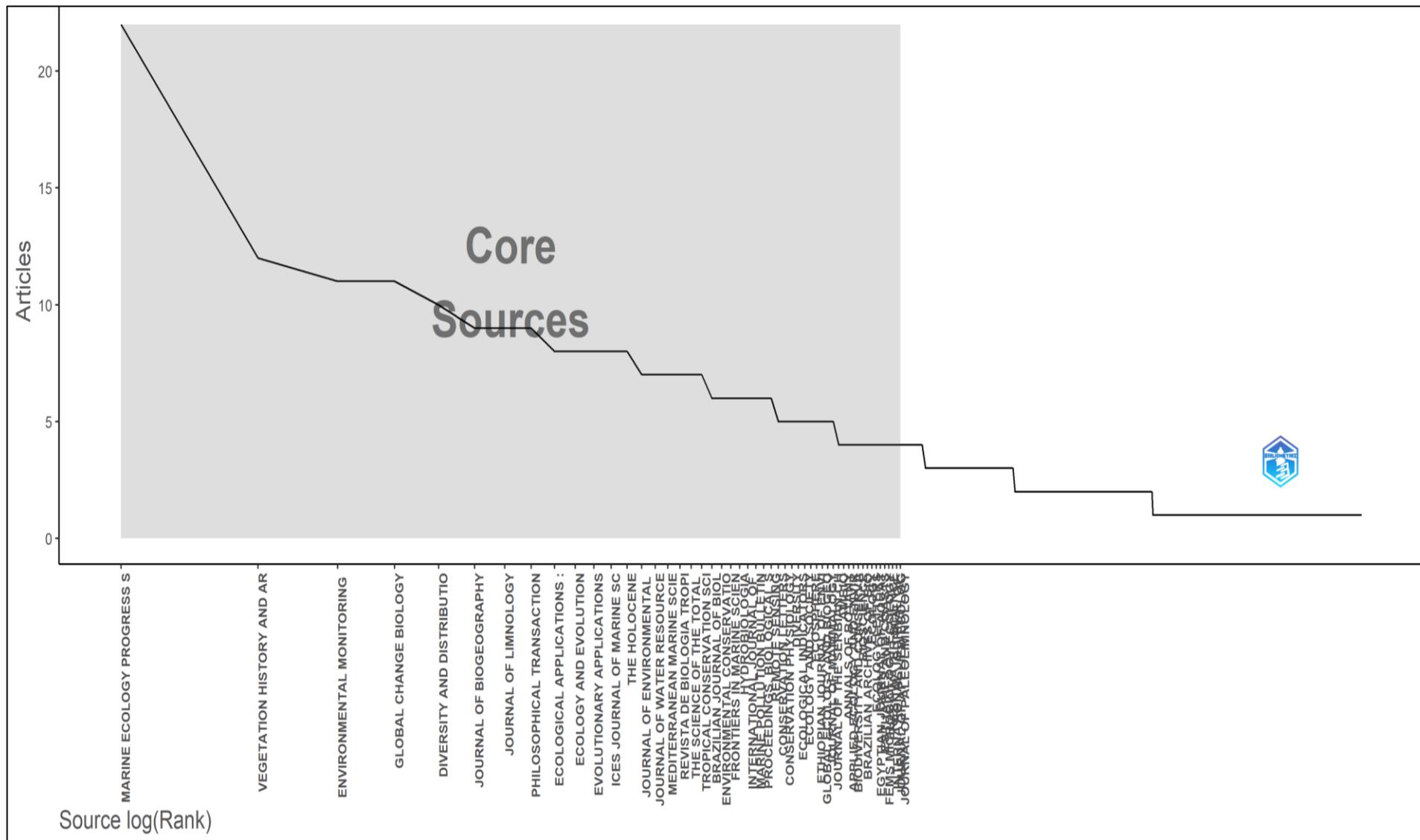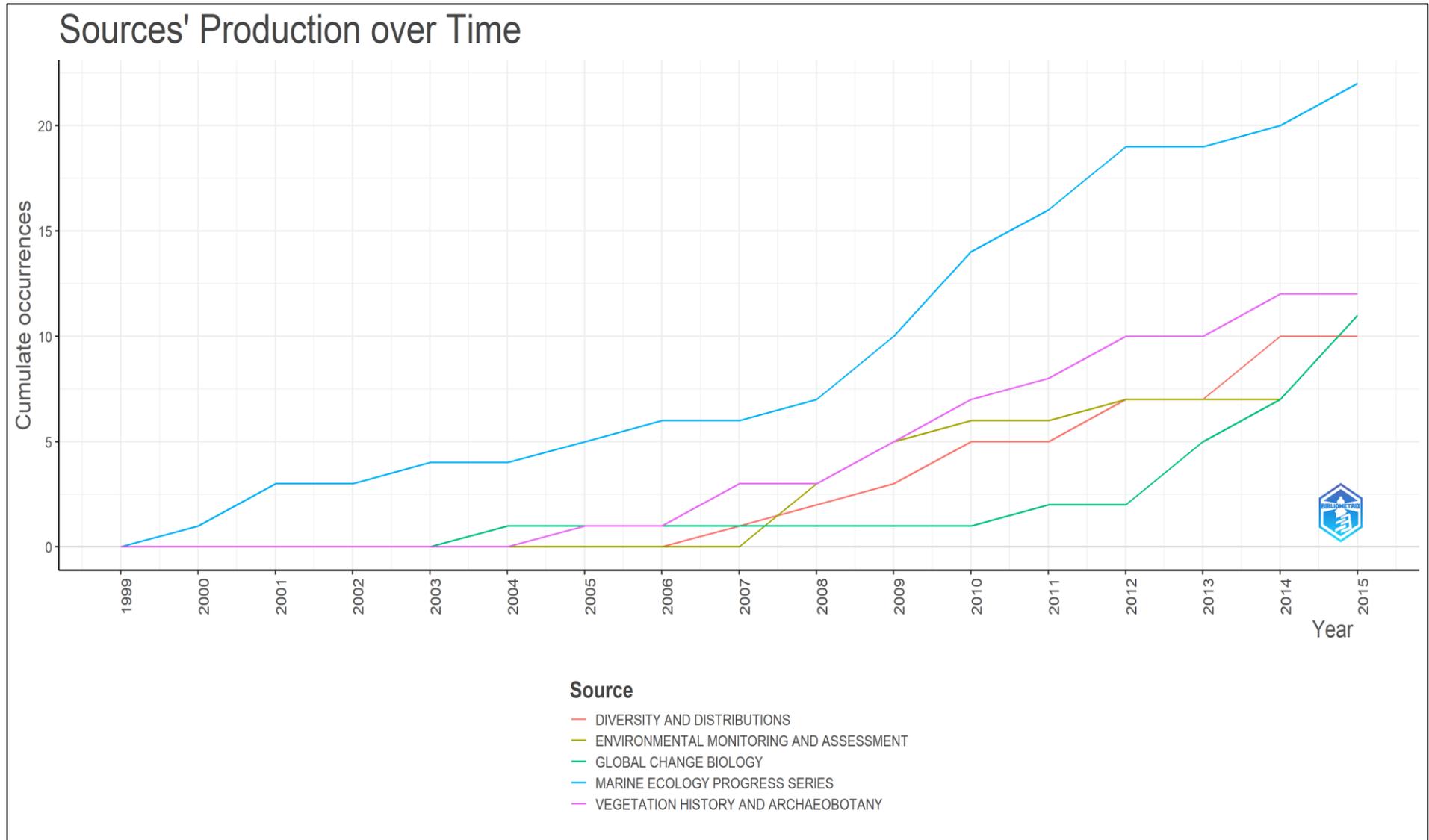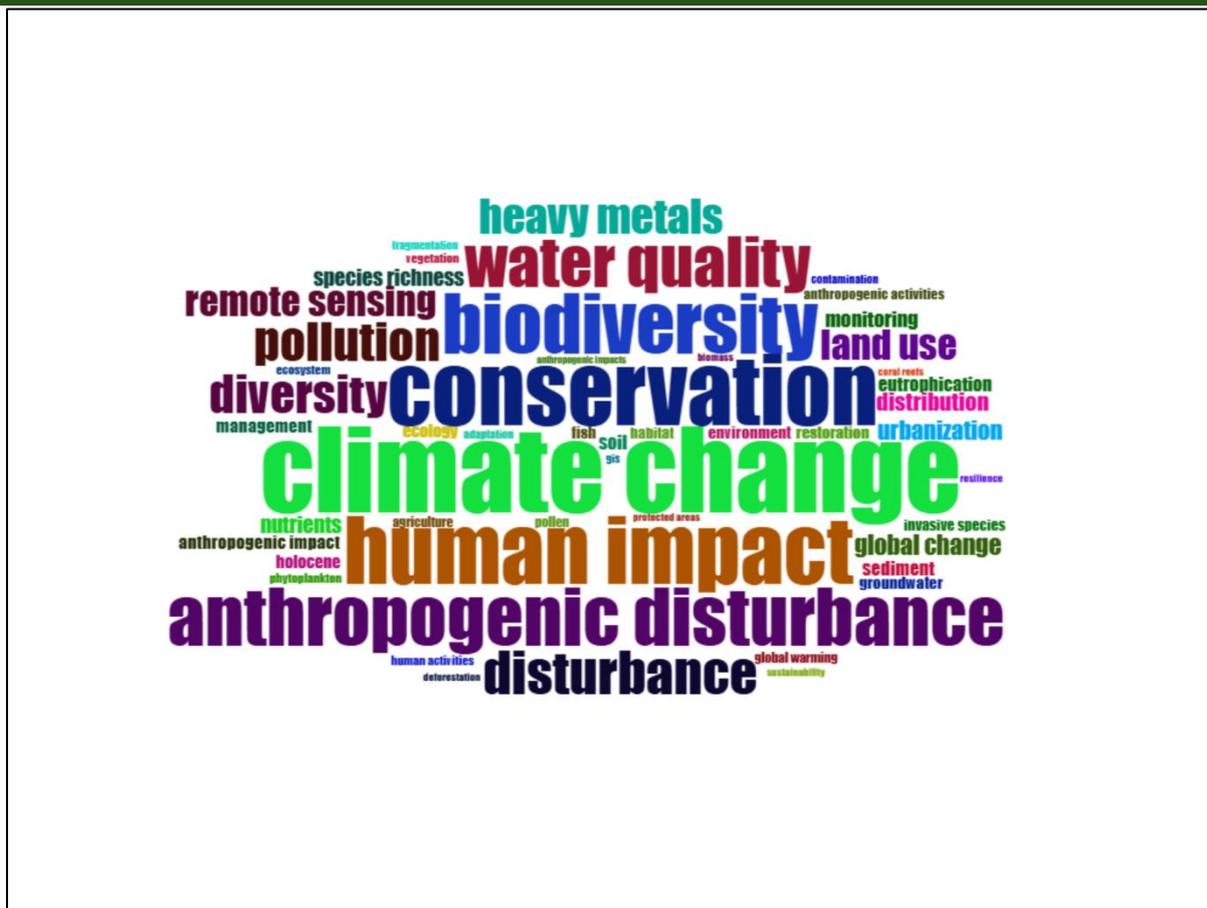
Figure 3c. Structural development of scientific literature on anthropogenic activities based on core sources by Bradford's Law.

Figure 3d. Structural development of scientific literature on anthropogenic activities based on sources production over time.

Figure 4. The most frequently occurring keywords related to environmental and ecological
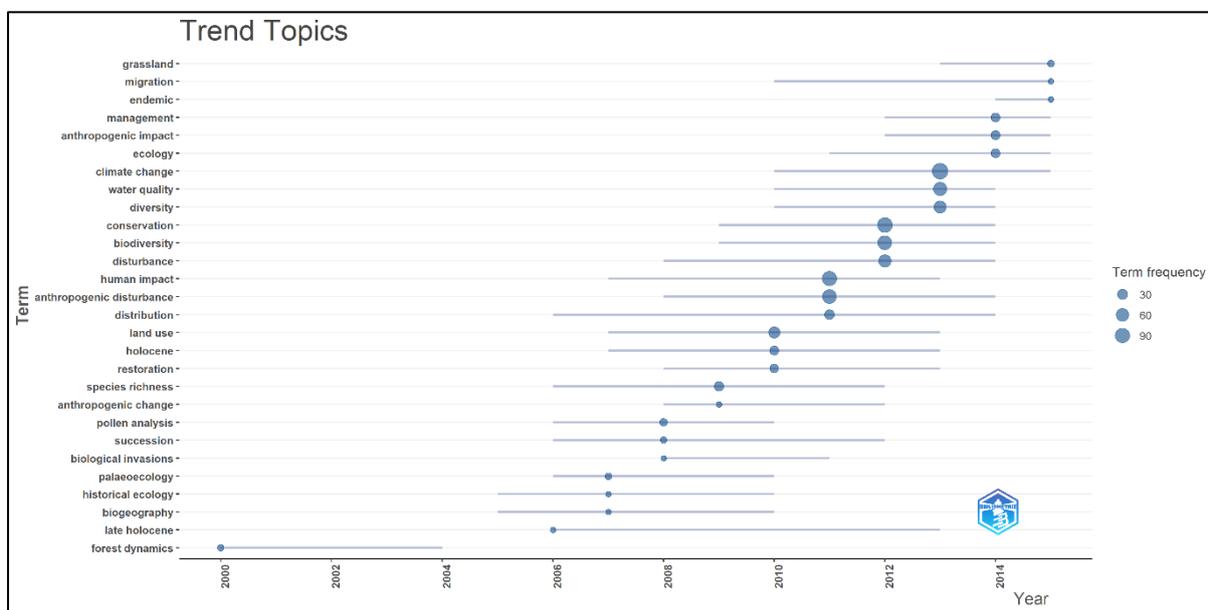
Figure 5. Temporal evolution of major research themes related to environmental change and anthropogenic impacts from approximately 2000 to 2015
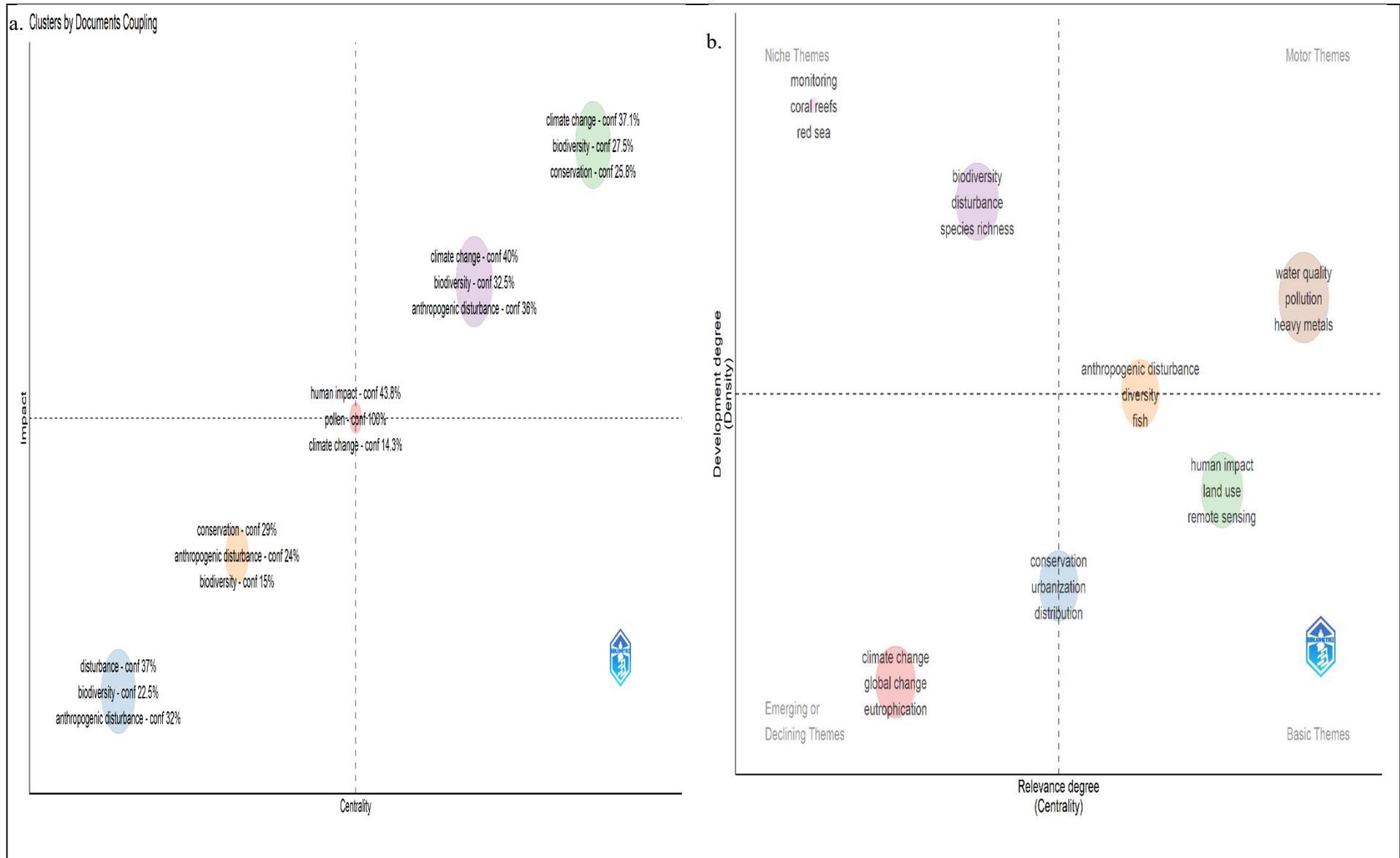
Figure 6. Bibliometric thematic structure (a) and cluster distribution based on keyword co-occurrence analysis (b).

Figure 7 illustrates how MCA converts multidimensional keyword data into a two-dimensional space, enabling the interpretation of conceptual relationships between research topics based on their proximity on the map. Stronger conceptual relationships are indicated by keywords that co-occur more frequently in scientific publications (Aria & Cuccurullo, 2017). Two major conceptual groupings are shown in the illustration. Keywords including anthropogenic activities, contamination, sediment, heavy metals, nitrogen, nutrients, groundwater, pollution, and water quality are found in the first cluster, which is located on the right side of the map. The biogeochemical effects of human activity and environmental contamination, especially in aquatic and coastal ecosystems, are the main research topics highlighted by this grouping. The second conceptual grouping, which is oriented toward the lower-right quadrant, contains terms like coral reefs, fish, vegetation, conservation, restoration, management, and resilience that are associated with ecosystem responses and management. This cluster may represent applied environmental management and monitoring techniques used to evaluate anthropogenic impacts, as suggested by closely related terms like land use, remote sensing, protected areas, and deforestation. On the other hand, paleoecological and historical environmental research are represented by keywords at the left of the picture, such as Holocene, pollen, and pollen analysis. These subjects appear to be conceptually more distant from the prevailing themes of current research, based on their relative separation from the main cluster. Overall, the conceptual structure map shows that the two interrelated areas of environmental pollution and ecosystem management are the focus of current anthropogenic impact research, with historical ecological reconstruction serving as a secondary study stream.
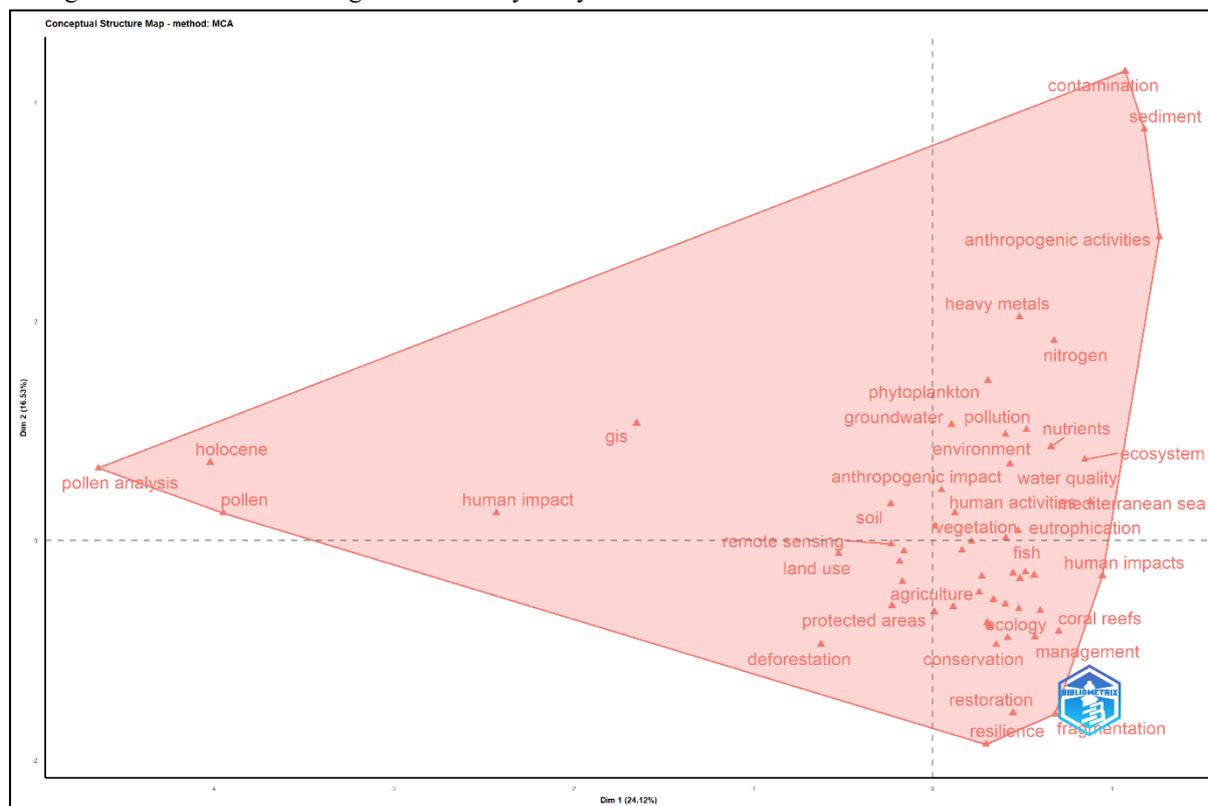
Figure 7. Conceptual structure map derived from Multiple Correspondence Analysis (MCA)

DISCUSSION

The widespread acknowledgement that human activity is a primary cause of ecological change is reflected in the network's prominence of keywords like biodiversity, climate change, and human impact. Human-caused factors, such as pollution, deforestation, land-use change, and greenhouse gas emissions, are frequently identified in scientific literature as the primary causes of ecosystem deterioration and biodiversity loss (IPBES, 2019; Steffen et al., 2015). According to Tan et al. (2023), bibliometric analyses of biodiversity research also emphasize anthropogenic disturbance and climate change as major environmental science themes. This suggests that current research is increasingly focused on comprehending the mechanisms through which human activities affect species distributions, ecological processes, and ecosystem stability. The network structure, where these keywords serve as hubs connecting many research subfields, further demonstrates this centrality. The clustering

patterns show how technical methods and environmental monitoring are integrated in the study of anthropogenic impacts. Keywords like "remote sensing," "monitoring," and "land-use change" show how geospatial technologies are becoming increasingly important for identifying ecological shifts and measuring human disturbances in coastal systems and landscapes (Pettorelli et al., 2014). Because they enable researchers to monitor significant environmental changes over time, remote sensing methods have become indispensable for evaluating environmental deterioration, such as deforestation, the loss of coastal habitat, and the demise of coral reefs. For instance, it has been demonstrated that land-use changes and climate changes have a substantial impact on mangrove forests and other important habitats in coastal ecosystems, leading to ecosystem degradation and heightened vulnerability of coastal settings (Alongi, 2015; Rahim et al., 2024).

Furthermore, a growing trend in environmental research toward ecosystem management and conservation techniques is reflected in the network's emphasis on sustainability, resilience, and restoration. Scientific interest in mitigation and adaptation strategies that improve ecosystem resilience and lessen environmental deterioration has grown as anthropogenic pressures increase (Folke et al., 2010). The interdisciplinary nature of studies on global environmental change is highlighted by bibliometric analyses of climate research, which also reveal that contemporary research clusters frequently link biodiversity, adaptation, and sustainability (Bornmann et al., 2020; Haunschild et al., 2016). This pattern shows that modern research focuses methods for ecosystem restoration and sustainable management in addition to studying the causes of environmental change. Overall, network visualization shows how anthropogenic disturbance research is organized around three interrelated domains: ecological consequences (such as biodiversity loss and ecosystem degradation), environmental drivers (such as climate change and land-use change), and management responses (such as sustainability and restoration) (IPBES, 2019). The intricacy of human-environment interactions and the necessity of coordinated multidisciplinary approaches to meet the issues posed by anthropogenic environmental change are highlighted by the considerable interconnection across these themes.

The dataset's strong yearly growth rate reflects the growing interest of scientists worldwide in human environmental change. A rapid increase in publishing output is sometimes seen as proof that a subject of study is growing and becoming more significant in both science and society (Bornmann & Mutz, 2014). Increasing publication and citation counts frequently indicate the creation of a research hotspot and the development of specialized knowledge domains within the scientific community, according to bibliometric studies conducted across a variety of fields (Donthu et al., 2021). This increase in anthropogenic environmental research is in line with growing worldwide concerns about pollution, ecosystem degradation, biodiversity loss, and climate change, all of which are closely related to human activity (Steffen et al., 2015). The documents' high citation rate indicates that many of this research has significantly influenced our present understanding of ecological responses and environmental change.

The dataset's authorship and collaboration patterns further emphasize how crucial interdisciplinary teamwork is to environmental research. Studies addressing anthropogenic consequences usually require partnerships among scientists from different disciplines, such as marine science, ecology, climate science, and environmental management, as seen by the relatively high number of co-authors per document. As larger research teams combine a variety of resources and experience to address complex environmental challenges, prior scientometric studies have demonstrated that collaborative research frequently results in better scientific impact and visibility (Wuchty et al., 2007). Because anthropogenic disturbances, such as pollution, habitat destruction, and climate-driven ocean shifts, work across interrelated biological and socio-environmental systems, such collaboration is especially crucial in marine and coastal investigations (Halpern et al., 2015). In order to comprehend the mechanisms, effects, and mitigation techniques related to human-driven environmental change, multidisciplinary study approaches are crucial.

The worldwide bibliometric data demonstrated the exponential expansion in environmental and climate-related research over the past 20 years is consistent with the sharp rise in yearly scientific output. According to studies looking at the literature on climate change, publishing outputs have skyrocketed, frequently doubling every five to six years as environmental problems became more pressing and scientific interest grew globally (Bornmann & Mutz, 2014; Haunschild et al., 2016). Therefore, the faster increase seen in Figure 2a is indicative of larger scientific reactions to increasing anthropogenic pressures such habitat destruction, greenhouse gas emissions, and stress on marine ecosystems (Steffen et al., 2015). According to Li et al. (2022), rising publication rates are typically seen as signs of increased societal relevance and policy urgency related to environmental challenges.

Figure 2b citation dynamics provide more evidence in favor of the field's concept of intellectual growth. Early high citation rates usually happen when groundbreaking studies provide conceptual frameworks that influence future lines of inquiry (Bornmann & Mutz, 2014). Similar findings are shown by bibliometric assessments of climate science and environmental degradation, which show that fundamental papers receive disproportionate citations before citation rates normalize as research issues widen and interdisciplinary participation rises (Haunschild et al., 2016). Scientific diffusion processes are typified by the S-shaped cumulative curve in Figure 2d, where knowledge production moves from innovation to rapid adoption and finally consolidation (Rogers, 2003).

These trends show how anthropogenic impact studies have progressed from localized environmental evaluations to integrated Earth-system research from the standpoint of marine science. While later research increasingly considers climatic connections, ecosystem resilience, and sustainability frameworks, earlier studies frequently concentrated on pollution or habitat modification. Environmental research has grown increasingly interdisciplinary, incorporating ecological, technological, and socioeconomic factors, according to extensive bibliometric evaluations (Donthu et al., 2021; Fu & Waltman, 2021). This shift explains the life-cycle curve's stabilization phase, during which growth continues but at a more specialized and structured rate.

Overall, the image shows that research on anthropogenic activities follows a traditional trajectory of scientific development: emergence, rapid expansion, and consolidation (Bornmann & Mutz, 2014). Growing publication output, stable citation trends, and cumulative growth saturation all point to a developed field of study that today supports policy formation, conservation planning, and applied management (IPBES, 2019). To comprehend and lessen human influences on ocean ecosystems, long-term datasets and interdisciplinary cooperation are required for tackling complicated marine environmental concerns (Halpern et al., 2015).

Bradford's Law, which argues that scientific literature is unevenly distributed and that a small number of extremely productive journals contribute a disproportionately large fraction of articles in each subject, is consistent with the dominance of a small number of journals seen in Figure 3 (Bradford, 1934). According to recent bibliometric research, key journals serve as the principal platforms for sharing fundamental knowledge and directing research agendas (Cobo et al., 2011; Donthu et al., 2021). In anthropogenic activities research, the existence of well-defined core sources is a sign of intellectual consolidation and the development of specialized publication venues that are essential to marine ecology and environmental science.

From the standpoint of marine science, the increased complexity of anthropogenic impact research is reflected in the concentration of important journals and rising output over time. Interdisciplinary integration is becoming more necessary for environmental studies tackling climate change, pollution, habitat degradation, and biodiversity loss (Steffen et al., 2015). Bibliometric evaluations show that while peripheral journals provide new or specialized viewpoints that expand disciplinary coverage, core journals frequently influence methodological norms and theoretical frameworks (Donthu et al., 2021). Therefore, as anthropogenic impact studies move from localized environmental evaluations to global Earth-system analysis, the rising production patterns displayed in figure 3d reflect both quantitative growth and topic diversification.

Additionally, the connection between impact and source productivity emphasizes how scientific advancement is cumulative. Influential journals get citations and solidify their pivotal position in academic networks as research communities develop, which helps to stabilize knowledge and increase the accessibility of important discoveries (Bornmann & Mutz, 2014). Such consolidation is crucial for anthropogenic marine research in order to translate scientific findings into conservation policies, environmental management plans, and frameworks for sustainable ocean governance (IPBES, 2019). Overall, Figure 3 shows that the bibliometric structure of anthropogenic activities research is mature, with core knowledge centers, growing publication networks, and steady temporal growth. These trends point to a well-established and developing field of study that can facilitate multidisciplinary responses to environmental problems caused by humans (Donthu et al., 2021). The figure's emphasis on human effect and climate change reflects the current scientific agreement that human activity is one of the major causes of biological change in marine and coastal ecosystems (IPCC, 2021). Ocean acidification, changing species ranges, and rising sea surface temperatures have all been connected to human-caused climate change, all of which have an impact on marine biodiversity and ecosystem functioning (IPCC, 2021). Furthermore, it is commonly acknowledged that human activities including resource extraction, coastal development, and pollution are major causes of anthropogenic disturbance in marine habitats (Halpern et al., 2015).

The significance of land-based anthropogenic inputs to marine ecosystems is further demonstrated by the inclusion of terms like pollution, heavy metals, nutrients, and water quality in the word cloud. Eutrophication, toxic pollution, and deteriorating ecosystem health results from runoff from urban wastewater, industrial discharge, and agriculture introducing pollutants and excess nutrients into coastal waters (Diaz & Rosenberg, 2008; Halpern et al., 2015). Furthermore, the emergence of phrases like "remote sensing" and "monitoring" shows the increasing dependence on cutting-edge technologies to monitor environmental change and evaluate the effects of human activity (Pettorelli et al., 2014). The observed shift in study themes reflects how environmental and marine science have evolved more broadly to meet the growing effects of human activity on ecosystems. It is now generally acknowledged that anthropogenic pressures are the main causes of ecosystem degradation and biodiversity decrease (IPBES, 2019; Steffen et al., 2015). The increasing awareness that environmental stressors are interrelated is also reflected in the popularity of terms like anthropogenic disturbance, water quality, and climate change (Halpern et al., 2015). Bibliometric assessments have shown a significant development of study themes connected to climate change and the environment, reflecting growing worldwide awareness (Haunschild et al., 2016).

Figure 6 thematic structure illustrates how the field of research on human influences on marine ecosystems is changing. The motor themes highlight anthropogenic contaminants and their ecological effects (Aria & Cuccurullo, 2017; Cobo et al., 2011). Heavy metal pollution and deteriorating water quality are major causes of ecological degradation (Halpern et al., 2015; Kennish, 2002). Remote sensing technologies are now frequently employed to monitor ecosystem disturbances (Pettorelli et al., 2014). The figure's specialist themes highlight the susceptibility of coral reefs to human stresses. Coral reefs are extremely vulnerable to pollution and climate change (Hughes et al., 2017; IPCC, 2021). Pollution channels and ecological effects are depicted in Figure 7 conceptual framework. Eutrophication and biodiversity loss may result from nutrient enrichment (Diaz & Rosenberg, 2008; Halpern et al., 2015). Conservation tactics and ecosystem resilience are shown in the second cluster. Restoration and protected areas are receiving more attention in research (Folke et al., 2010; Hughes et al., 2017).

CONCLUSION

Through a thorough bibliometric analysis, this study aimed to methodically investigate the intellectual framework, thematic development, and scientific advancement of research on anthropogenic activities and their effects on the environment. The study effectively addressed its major goal of mapping important research trends, conceptual areas, and collaborative patterns that define the discipline by examining 1,000 documents published between 1999 and 2015. The results show that anthropogenic environmental change research has developed into a well-established and quickly growing field of study. Sustained scholarly attention and the growing worldwide relevance of environmental concerns caused by human activity are shown in the high annual growth rate and significant citation effect. Knowledge generation in this subject is rigorous and extremely collaborative, as evidenced by the predominance of journal publications and the wide network of contributing writers. These trends highlight how environmental research is interdisciplinary, requiring integrated methods from several scientific fields due to the complexity of human-environment interactions. Thematic and conceptual assessments show that the discipline is organized around several major research areas, with water quality, biodiversity, human influence, and climate change emerging as prominent and closely related issues. These subjects represent the wide range of anthropogenic impacts on natural systems and act as focal points connecting different subfields. The literature's dual focus on comprehending the causes and effects of environmental degradation as well as the tactics needed for mitigation and sustainability is highlighted by the identification of two primary conceptual domains: ecosystem management and environmental contamination. A distinct shift in study concentration over time is further demonstrated by temporal analysis. While more recent research has focused on modern concerns including climate change, biodiversity loss, and applied ecosystem management, earlier studies stressed historical and paleoecological viewpoints. This development represents a more general shift in environmental science from descriptive and reconstructive methods to research that is solution-focused and pertinent to policy. Advances in environmental monitoring and data processing enable more accurate evaluations of anthropogenic consequences are also reflected in the growing prominence of technical techniques like remote sensing. The analysis also reveals a clearly defined bibliometric structure that is consistent with a developed scientific subject and is typified by core journals and well-established information hubs. The concentration of significant research inside important sources is confirmed by the application of Bradford's Law and thematic mapping, which also shows the ongoing growth

of ancillary contributions that enhance the richness of the subject. All things considered, this bibliometric mapping offers insightful information about the development, organization, and focus of anthropogenic environmental change research. The results highlight the vital significance of ongoing interdisciplinary cooperation and persistent scientific investigation in tackling the intricate problems caused by human activity in ecosystems. By expanding analysis to more recent datasets, utilizing cutting-edge techniques, and delving deeper into the incorporation of scientific information into environmental policy and sustainable management methods, future study may build on these discoveries.

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